IODP Expedition 369: Australia Cretaceous Climate and Tectonics

Site U1512 Summary

Background and Objectives

IODP Site U1512 (34°1.6407′S, 127°57.7604′E, proposed Site WCED-4A) was cored to obtain a continuous Upper Cretaceous record of marine black shales in the Great Australian Bight (GAB) across Oceanic Anoxic Event (OAE) 2, which straddles the Cenomanian/Turonian Boundary interval (CTBI). The Site U1512 sediment record will be compared with coeval Expedition 369 sequences cored on the Naturaliste Plateau and in the Mentelle Basin to characterize the geochemical and biological responses to extreme global carbon cycle perturbations in different paleoceanographic settings at high southern latitudes.

Operations

Site U1512 consisted of a single hole, U1512A (34°1.6406′S, 127°57.7605′E; 3071 m water depth) that was cored with the rotary core barrel (RCB) system. The vessel arrived at Site U1512 at ~0500 h on 7 October with the thrusters down and the official sea voyage from Hobart, Australia, over at 0530 h. The beacon was deployed at 0610 h, and after assembling RCB bottom-hole assembly (BHA), we began lowering the drill string towards the seafloor at 0900 h. Hole U1512A was started at 2120 h on 7 October, following two unsuccessful attempts to tag the seafloor. The water depth was determined to be 3070.9 m. Cores U1512A-1R and 2R were shortly on deck at 2240 h and 2340 h, respectively. Core U1512A-1R recovered 0.66 m (7% recovery) and 2R recovered 2.03 m (21% recovery) to a depth of 19.2 m. Subsequent cores showed a sharp increase in recovery (mostly >90%). The original plan was to advance to 570 m; however, it became apparent during coring operations that the Late Cretaceous sedimentary section was more expanded than predicted. Following revisions to coring depth estimates and safety panel approval, the hole was deepened to 700 m. RCB coring continued through Core 73R to 700.8 m at 1915 h on 13 October. In total, 73 RCB cores were retrieved with 631.86 m of material recovered from 700.8 m drilled (90% recovery).

After releasing the RCB bit at the bottom of the hole and bringing the drill pipe up to logging depth (69.9 m), a modified triple combination tool string was assembled with the following tools: Hostile Environment Natural Gamma Ray Sonde (HNGS), High-Resolution Laterolog Array (HRLA), Dipole Sonic Imager (DSI), Hostile Environment Litho-Density Sonde (with source) (HLDS), Enhanced Digital Telemetry Cartridge (EDTC), logging equipment head-q tension (model QT) (LEHQT), and a centralizer for centralizing the DSI and the HRLA. In this modified tool string, the HNGS was moved to the bottom of the tool string and the DSI was added from the Formation Micro-Scanner (FMS) tool string. The tools were assembled, tested, and deployed at 0435 h on 14 October. A downlog was performed from just above the seafloor to 698.4 m. The hole was then logged up for a short calibration pass (~100 m), run back to the bottom, and logged up to just below the end of the drill pipe, where the caliper was closed prior to reentering the drill pipe. The tools were pulled from the hole and were back at the surface at 1130 h on 14 October, and by 1345 h the equipment was rigged down. The drill string was then pulled out of the hole, clearing the seafloor at 1410 h. The acoustic beacon was released and recovered on deck at 1736 h. At 2255 h on 14 October, the end of the drill pipe cleared the rig floor. The rig floor was secured for transit at 2300 h, ending Hole U1512A and Site U1512. Overall, 7.7 d (7–14 October) were spent at Site U1512.

Principal Results

Lithology

The sedimentary sequence of Hole U1512A is divided into two main lithologic units. Unit I is a 10.06 m thick sequence of Pleistocene pinkish to white calcareous ooze with sponge spicules; it extends from the beginning of the hole up to 10.06 m CSF-A (Section 1R-1, 0 cm, through Section 2R-1, 46.00 cm). The unit consists of medium and thick beds with no distinctive sedimentary structures; it exhibits no bioturbation and it is massive and structureless. In this unit, biogenic grains are the major constituent and are comprised of dominant calcareous nannofossils, abundant foraminifera, and common sponge spicules. Unit II is a 690.32 m thick sequence of silty clay that gradationally transitions into silty claystone (Section 2R-1, 46.00 cm, through Section 73R-CC, 24.00 cm to bottom of the hole). This unit is black to dark gray mottled silty claystone composed of quartz, clay minerals, pyrite, siderite, and dolomite with varying degrees of bioturbation. Micropaleontological analysis indicates a Late Cretaceous (Santonian to Turonian) age for this unit. Lithologic Unit II is further subdivided into Subunits IIA (silty clay) and IIB (silty claystone) based on the degree of sediment lithification. Subunit IIA is 75.10 m thick and is composed of very dark greenish grey to black, unlithified silty clay. This subunit is characterized by the presence of pyrite both as nodules and in a disseminated form within the silty clay. Zeolite, foraminifera, calcareous nannofossils, and sponge spicules are present in trace amounts throughout the subunit. Inoceramid bivalve fragments and alteration halos occur frequently throughout the subunit. Subunit IIB is 615.22 m thick and is composed of lithified black silty claystone. Included in this subunit are 23 thin to medium beds of glauconitic and sideritic sandstone beds that are no greater than 32 cm in thickness, mostly massive, and exhibit normal grading. Bioclast traces present in this subunit include foraminifera, calcareous nannofossils, radiolarians, sponge spicules, and organic matter.

Biostratigraphy and Micropaleontology

Samples from all core catchers in Hole U1512A were analyzed for calcareous nannofossil, planktonic, and benthic foraminifera. In addition, calcareous nannofossil assemblages were evaluated from split core sections. Observations of other distinctive and potentially age or environmentally diagnostic microfossil groups, such as organic-walled dinoflagellate cysts (dinocysts), radiolaria, fish debris, and inoceramid prisms, were also made in all core catcher samples. Calcareous nannofossil datums form the chronologic framework for Hole U1512A as they are most consistently present. In contrast, planktonic foraminifera are rare, but where present, give ages consistent with those from calcareous nannofossils. Similarly, rare dinocyst taxa from Cores 47R to 70R (~440–672 m CSF-A) and radiolarians from Cores 5R to 35R (~38–333 m CSF-A) provide valuable additional age confirmation of Late Cretaceous sediments.

Core 1R is in calcareous nannofossil Zone CN15 and planktonic foraminiferal Zone Pt1b, and is upper Pleistocene/Holocene. Cores 2R–4R are barren of calcareous nannofossils but contain rare planktonic foraminifera of both Cenozoic and Cretaceous species, which together with mixed radiolarian assemblage ages, indicate downhole contamination during drilling. Cores 5R and 6R are upper Santonian and lowermost Campanian calcareous nannofossil Zone CC17. Cores 7R to 11R (~57–104 m CSF-A) are assigned to latest Coniacian–Campanian calcareous nannofossil Zones CC16–CC17. Cores 12R–16R (~105–154 m CSF-A) are in Zone CC15 spanning the uppermost Coniacian and lowermost Santonian. Cores 17R–20R (to ~192 m CSF-A) are Zone CC14 of Coniacian age. Cores 21R–30R are mostly barren of all age diagnostic carbonate microfossils but likely span the Coniacian/Turonian boundary. Cores 31R to 73R (the base of the hole, 701.38 m CSF-A) are Turonian, based on calcareous nannofossils in Cores 31R–48R spanning Zone CC12, Cores 49R–73R in Zone CC11, and Cores 65R–73R in Zone CC10c. The sediment accumulation rate for the Santonian is 36 m/My (Zones CC17-CC16), and 19 m/My (Zone CC15). The interval from the uppermost Coniacian to middle Turonian, encompassing Zones CC14 and CC13, has an average sediment accumulation rate of 63 m/My. Sediment accumulation rates accelerated markedly in the lower to middle Turonian Zone CC12, to 272 m/My.

Tubular agglutinated forms dominate benthic foraminiferal assemblages at Site U1512 and indicate either a lower to mid-bathyal environment or a marginal/restricted environment throughout the Late Cretaceous.

Paleomagnetism

The natural remanent magnetization of all archive-half core sections and 21 discrete samples collected from the working halves of Hole U1512A were measured. The archive halves were stepwise treated with up to 30 mT alternating field (AF) demagnetization and measured with the pass-through superconducting rock magnetometer at 5 cm intervals. The NRM intensity of the section is relatively weak and varies from 1.5×10^{-5} to 7.8×10^{-2} A/m, with a mean of 5.5×10^{-4} A/m. The demagnetization results show that the drilling-induced magnetic overprints can generally be removed by AF demagnetization at 10–20 mT. Inclinations of the characteristic remanent magnetizations (ChRMs) are predominantly negative, indicating predominantly normal polarity. The top ~80 m of the hole display a very noisy signal because of the significant coring disturbance (biscuiting) introduced by the rotary coring process. Positive inclination values occur between 0–75, 175–190, and 256–259 m CSF-A. The intervals from ~0–75 and 175–100 m CSF-A also exhibit sporadic or consecutive negative ChRM inclinations mixed with the dominantly positive inclinations making it impossible to assign magnetic polarity. The interval between 256 and 259 m CSF-A exhibits consistent downward-pointing paleomagnetic inclinations, defining a zone of reversed polarity, probably associated with a short geomagnetic excursion. Shipboard micropaleontological studies suggest that Core 5R (38.4–47.4 m CSF-A) is Santonian and the base of Core 73R is early Turonian. Therefore, the majority of the sedimentary cores (from 38.4 to ~700 m CSF-A) document the uppermost segment of the 41.5 My Cretaceous Normal Superchron (CNS) C34n.

Petrophysics

Physical property data were obtained with the Whole-Round Multisensor Logger (WRMSL), natural gamma radiation (NGR) logger, *P*-wave velocity caliper, Section Half Multisensor Logger (SHMSL) and discrete samples. WRMSL *P*-wave measurements below Core 11R were discontinued due to poor contact between the RCB core sections, their liners, and the caliper. NGR values average 32.8 counts/s, and bulk density estimates from gamma ray attenuation (GRA) values average 1.7 g/cm^3. GRA derived bulk density values in siltstone/claystone do not exceed 2.2 g/cm^3, while in siderite nodules and glauconitic sandstones they increase up to 3.28 g/cm^3. WRMSL magnetic susceptibility (MS) values average 9.35 IU and do not exceed 16 IU in claystone and siltstone, but suddenly increase up to 253.58 IU in the glauconitic sandstone and siderite; point MS measurements from the SHMSL agree with the trends. At scales >10 m, the NGR and MS records do not correlate over silty/clayey intervals from Cores 3R to 15R, possibly because of the high abundance of pyrite differentially influencing the MS values. The NGR and GRA records display parallel trends in this interval. From Core 16R to 62R, pyrite abundance markedly decreases and all three data types (MS, NGR, and GRA) display similar trends. From Core 63R to 73R, both the NGR and the MS values decrease, while GRA remains stable. At shorter scales (<10 m), MS, GRA, and NGR show high amplitude cycles of 3–5 m thickness from Cores 10R to 19R, Cores 34R to 43R, and Cores 62R to 73R. The range of *P*-wave velocities in the silty claystone range from 1670 to 2346 m/s, although faster velocities (3397–5774 m/s) were obtained for the discrete layers of sideritic sandstone. High resolution (2 cm) reflectance spectroscopy and colorimetry data from archive-half core sections display high amplitude variability. On average, three discrete moisture and density (MAD) samples were taken from each core. Overall, the MAD results show that the bulk density increases, while grain density and porosity decrease. The range of bulk densities obtained for the dark silty claystone are 1.54–2.37 g/cm^3, and the density of the sideritic sandstone intervals ranges from 3.21–3.49 g/cm^3. The porosities obtained for the silty claystone are 28%–65%, with most measurements between 40%–48%. The porosity of the sideritic sandstones ranges from 5%–13%.

One downhole logging run measured NGR, density, sonic velocity, and resistivity values of the borehole wall using a modified triple combination tool string. Excellent borehole stability and favorable low heave weather conditions permitted logging of the entire open borehole. Inclinometer readings progressively increase from roughly 0° above 210 m WMSF to 27° near the base of the hole, indicating that the borehole orientation deviated from vertical during coring.

Background trends in density, NGR, and resistivity logs are relatively stable in the upper 300 m of the borehole. Below that interval, each of those three logs records minimum values near 325 m WMSF, and then increase downhole to plateaus approaching maxima for the well. Additionally, the density and resistivity logs preserve several dozen thin spikes in values that likely correspond to the thin sideritic and glauconitic sandy beds commonly observed in several intervals of the core. In general, downhole measurements record trends that are similar to those observed in the physical properties measured from the cores, such as meter-scale cyclicity in NGR, and provide a continuous petrophysical stratigraphy to span occasional gaps in core recovery.

Geochemistry

A total of 73 headspace gas samples were taken for routine safety monitoring and Cores 1R to 9R were broadly free of interstitial gas. Methane was the dominant gas detected (up to 104,000 ppmV) with very minor ethane and occasional propane (up to 653 and 148 ppmV, respectively). Methane:ethane ratios suggest a transition from biogenic production above ~470 m CSF-A to possible thermogenic sources below that depth. For interstitial water (IW) analyses, 46 whole-round samples were taken. As a result of sediment lithology, IW yield was low for the majority of the cores below 12R (~115 m CSF-A), with the final IW sample taken from Core 59R (~560 m CSF-A). The salinity of IW samples generally decreased with depth due to decreases in sulfate (SO_4^{2-}), magnesium (Mg), and potassium (K) concentrations. The dissolved Mg, K, and boron (B) concentration profiles reflect alteration of volcanic material and clay mineral formation. Sulfate is readily depleted within the upper ~100 m (Core 10R) of the sedimentary column due to intense bacterial SO_4^{2-} reduction, which is accompanied by synchronous increases in ammonium (NH_4^+), alkalinity, and lithium (Li), along with high barium (Ba) values when SO_4^{2-} is exhausted. Alkalinity ranges from 4.4–16.52 mM with a maximum at 93.55 m CSF-A, and pH ranges from 7.76–7.97, with a slight decrease downhole; both measurements were limited to the top ~130 m because of the small IW volumes obtained from deeper samples. The dissolved calcium (Ca) and to a lesser degree strontium (Sr) concentration profiles show increasing concentrations towards 300 m CSF-A, which are more than likely due to carbonate diagenesis. Decreasing concentrations of Ca and Sr below 300 m CSF-A indicate carbonate dissolution/recrystallization may prevail at depth. Dissolved silicon (Si) shows a short positive excursion between 310.68 m CSF-A and 329.27 m CSF-A reflecting the presence of biogenic opal A in the sediment; lower values below Core 35R may be due to opalA/CT transformation. Elevated manganese (Mn) concentrations clearly demonstrate the reducing character of the whole sedimentary sequence.

A total of 72 sediment samples were collected from Cores U1512A-1R through 73R. $CaCO_3$ content varies from 0.06 to 6.66 wt%, with the exception of Core 1R, which is composed of a calcareous ooze with 91% $CaCO_3$. The low carbonate percentages between Cores 2R and 73R reflect the very low contribution of calcareous nannofossil and foraminiferal components to the sediment. The total organic carbon (TOC), which is predominantly terrestrially derived, ranges from 0.20 to 1.31 wt%, and total nitrogen (TN) ranges from <0.01 to 0.10 wt%. The TOC/TN ratio shows a general decrease with depth. This trend is likely caused by decomposition of nitrogen-containing terrestrial organic matter that released carbon as methane but retained the produced NH_4^+ in clays.

Stratigraphic correlation

Only one hole was drilled at Site U1512 with the RCB system. Recovery was excellent, exceeding 100% in 24 of the 73 cores recovered, and total recovery was 90%. Distinctive features for correlation included large scale (>10 m) trends and changes of variable amplitude on shorter length scales (1–5 m) in NGR and MS data, as well as distinct peaks corresponding to sandstone layers. Despite being unable to correlate cored intervals, recognition of matching features in NGR records from the cores and wireline log in Hole U1512A permitted a correlation of cored material (m CSF-A) to the wireline matched depth below seafloor (m WMSF).